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Cté

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(54) POINT CLOUD MODELING BASED ON USER-PROVIDED SEED

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(52) **U.S. Cl.**
CPC ***G06T 17/00*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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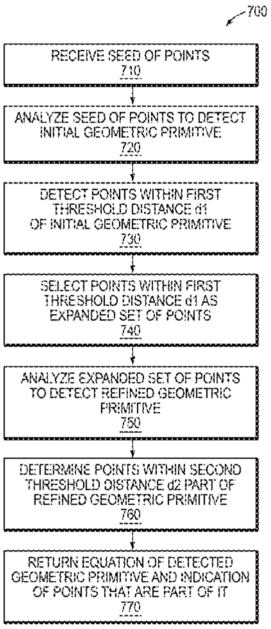
(57) **ABSTRACT**

In one embodiment, a semi-automated technique is used to reconstruct a vector-based model from a point cloud that represents a physical subject. At least a portion of the point cloud is displayed. A selection of a seed of points that correspond to a particular physical feature of the physical subject is received from a user. The selection is received with a flashlight virtual tool having a field of view. An automatic detection of a geometric primitive is performed based on the seed of points. The automatic detection uses an iterative algorithm that detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points, and detects a refined geometric primitive based on the expanded set of points. A vector-based model is produced using the detected geometric primitive.

22 Claims, 11 Drawing Sheets


700
RECEIVE SEED OF POINTS
710
ANALYZE SEED OF POINTS TO DETECT INITIAL GEOMETRIC PRIMITIVE
720
DETECT POINTS WITHIN FIRST THRESHOLD DISTANCE d1 OF INITIAL GEOMETRIC PRIMITIVE
730
SELECT POINTS WITHIN FIRST THRESHOLD DISTANCE d1 AS EXPANDED SET OF POINTS
740
ANALYZE EXPANDED SET OF POINTS TO DETECT REFINED GEOMETRIC PRIMITIVE
750
DETERMINE POINTS WITHIN SECOND THRESHOLD DISTANCE d2 PART OF REFINED GEOMETRIC PRIMITIVE
760
RETURN EQUATION OF DETECTED GEOMETRIC PRIMITIVE AND INDICATION OF POINTS THAT ARE PART OF IT
770

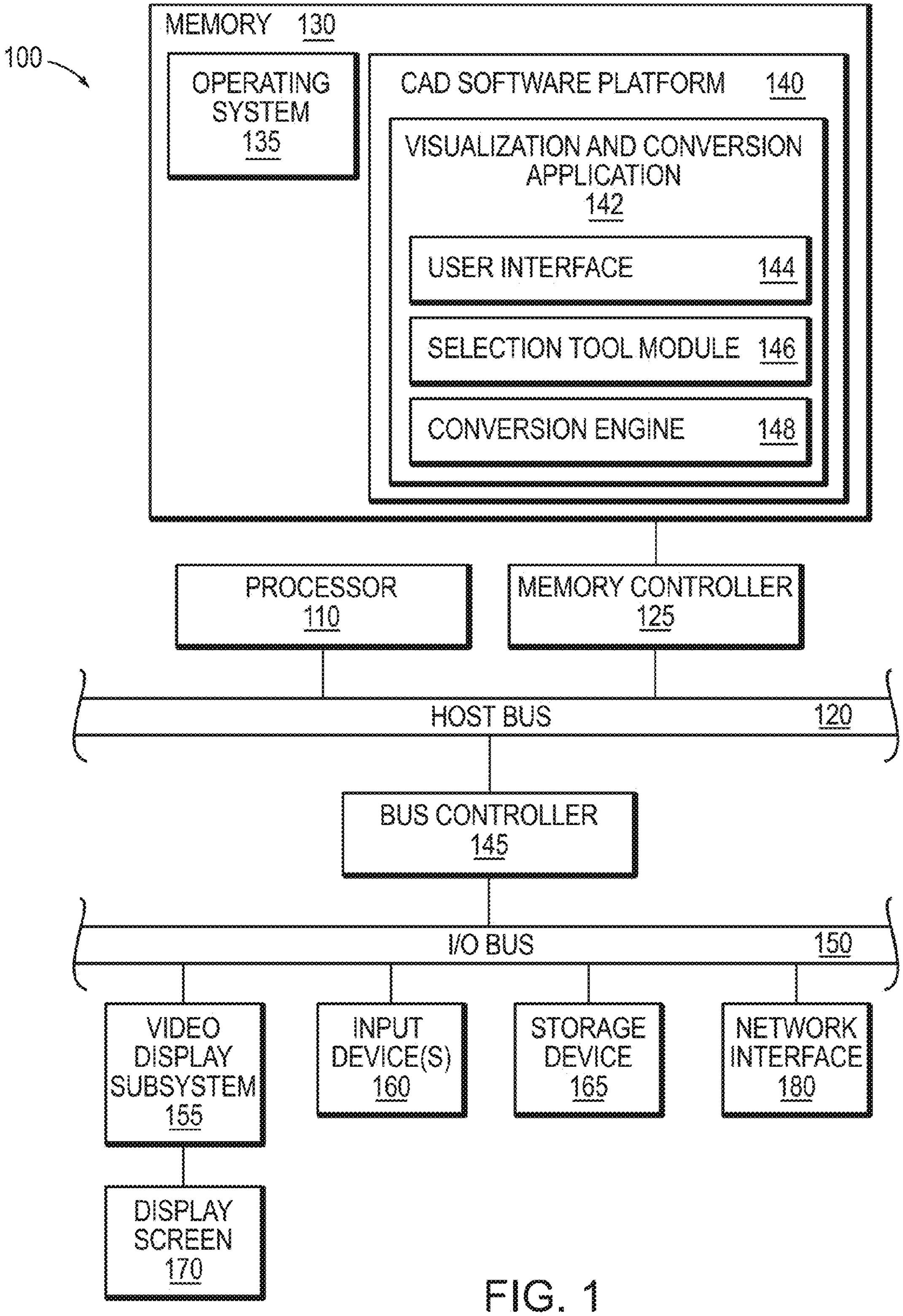

100
MEMORY 130
OPERATING SYSTEM 135
CAD SOFTWARE PLATFORM 140
VISUALIZATION AND CONVERSION APPLICATION 142
USER INTERFACE 144
SELECTION TOOL MODULE 146
CONVERSION ENGINE 148
PROCESSOR 110
MEMORY CONTROLLER 125
HOST BUS 120
BUS CONTROLLER 145
I/O BUS 150
VIDEO DISPLAY SUBSYSTEM 155
INPUT DEVICE(S) 160
STORAGE DEVICE 165
NETWORK INTERFACE 180
DISPLAY SCREEN 170

FIG. 1

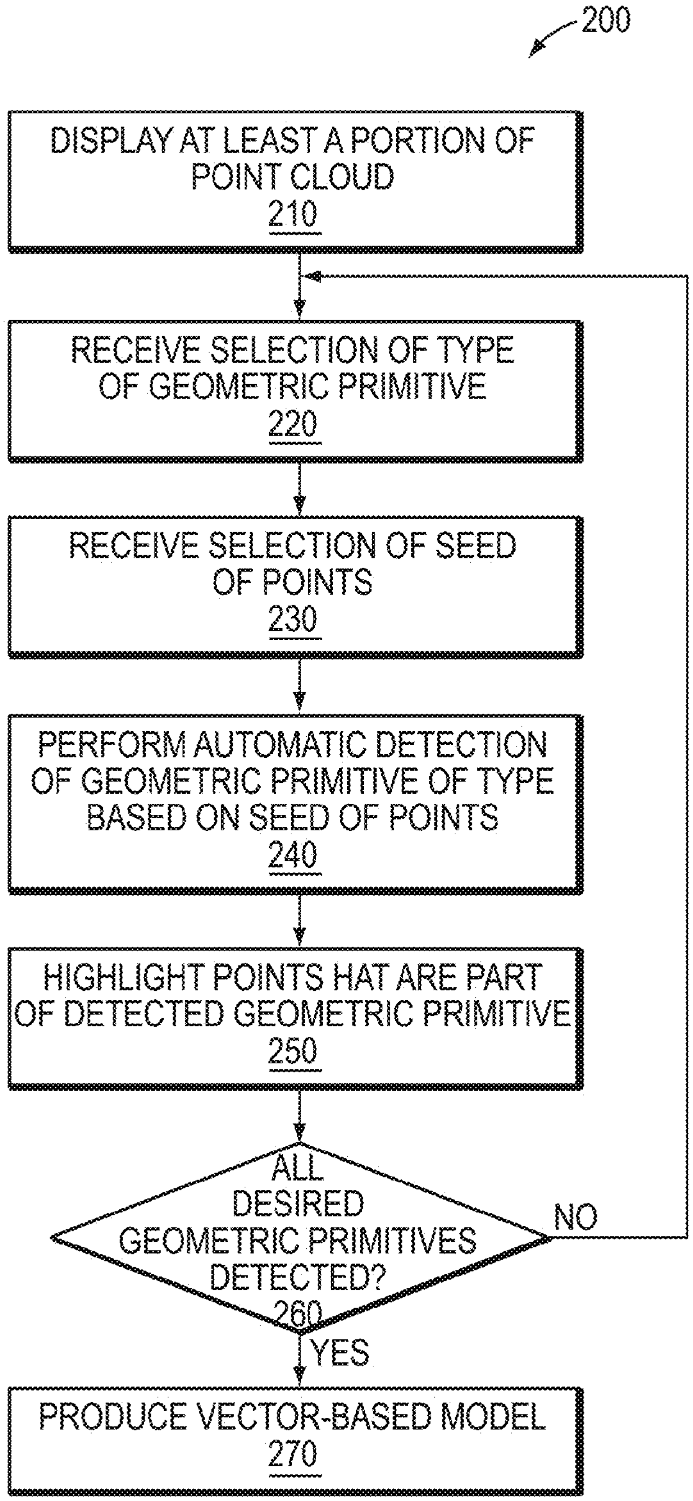

200
DISPLAY AT LEAST A PORTION OF POINT CLOUD
210
RECEIVE SELECTION OF TYPE OF GEOMETRIC PRIMITIVE
220
RECEIVE SELECTION OF SEED OF POINTS
230
PERFORM AUTOMATIC DETECTION OF GEOMETRIC PRIMITIVE OF TYPE BASED ON SEED OF POINTS
240
HIGHLIGHT POINTS HAT ARE PART OF DETECTED GEOMETRIC PRIMITIVE
250
ALL DESIRED GEOMETRIC PRIMITIVES DETECTED?
260
NO
YES
PRODUCE VECTOR-BASED MODEL
270

FIG. 2

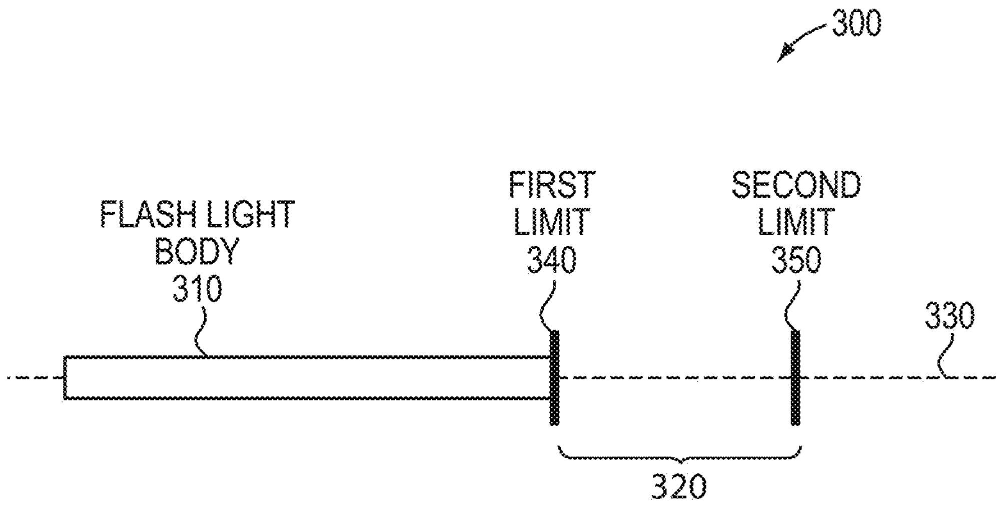

300
FLASH LIGHT BODY 310
FIRST LIMIT 340
SECOND LIMIT 350
330
320

FIG. 3

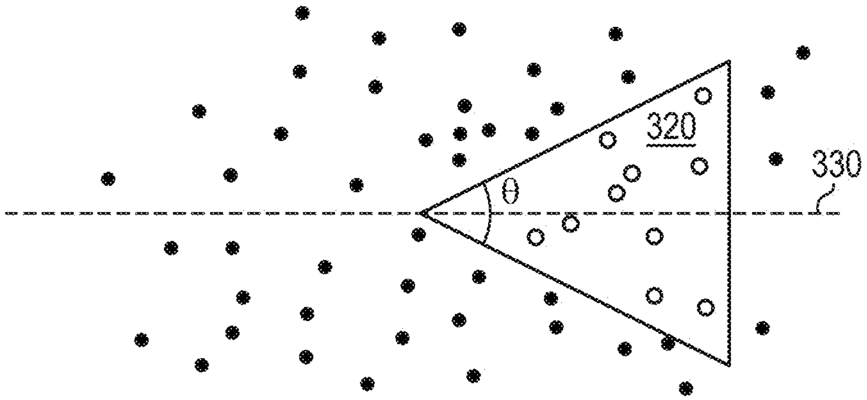


FIG. 4

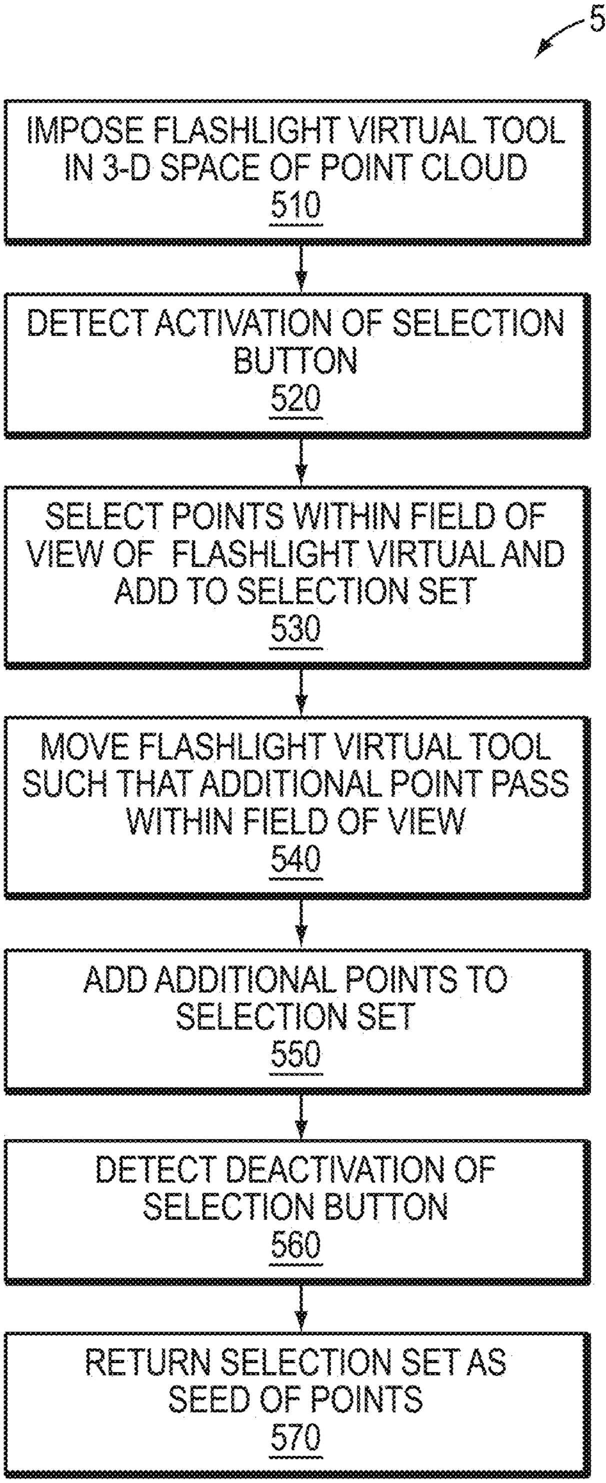

500
IMPOSE FLASHLIGHT VIRTUAL TOOL IN 3-D SPACE OF POINT CLOUD 510
DETECT ACTIVATION OF SELECTION BUTTON 520
SELECT POINTS WITHIN FIELD OF VIEW OF FLASHLIGHT VIRTUAL AND ADD TO SELECTION SET 530
MOVE FLASHLIGHT VIRTUAL TOOL SUCH THAT ADDITIONAL POINT PASS WITHIN FIELD OF VIEW 540
ADD ADDITIONAL POINTS TO SELECTION SET 550
DETECT DEACTIVATION OF SELECTION BUTTON 560
RETURN SELECTION SET AS SEED OF POINTS 570

FIG. 5

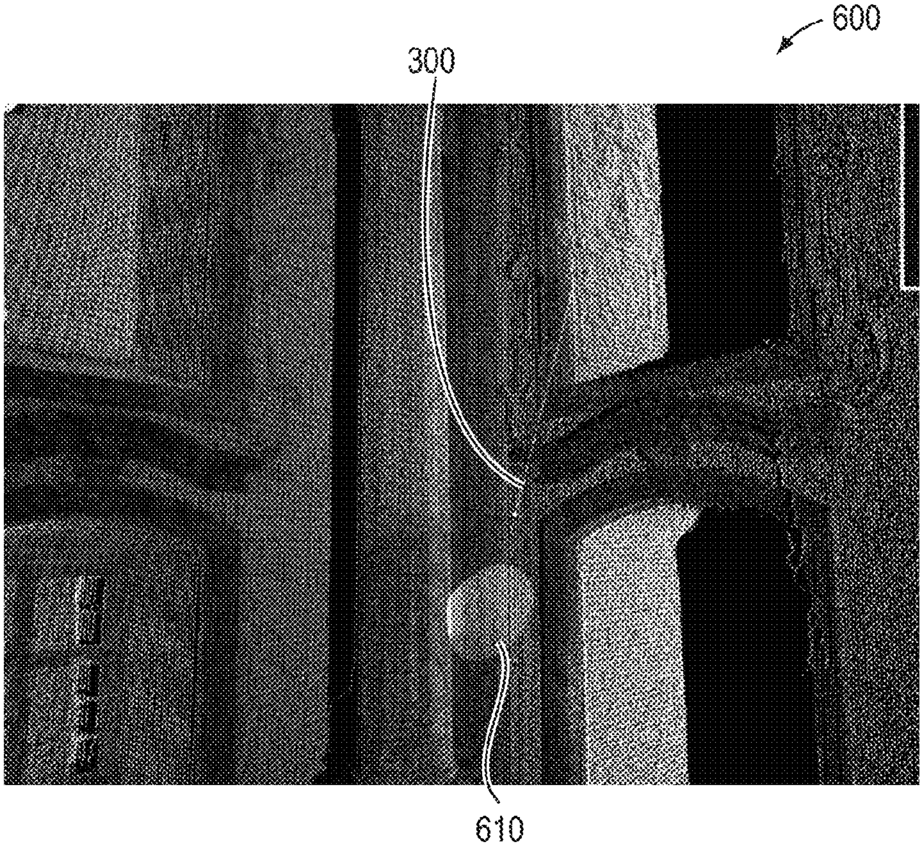


FIG. 6A

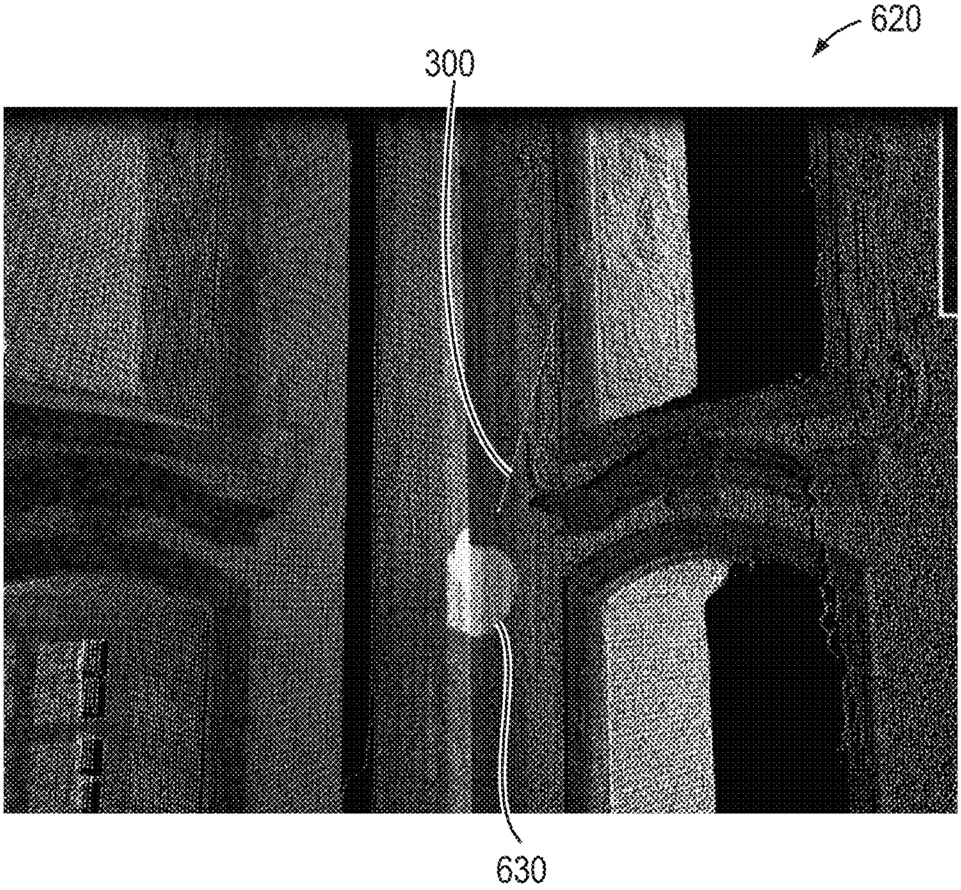


FIG. 6B

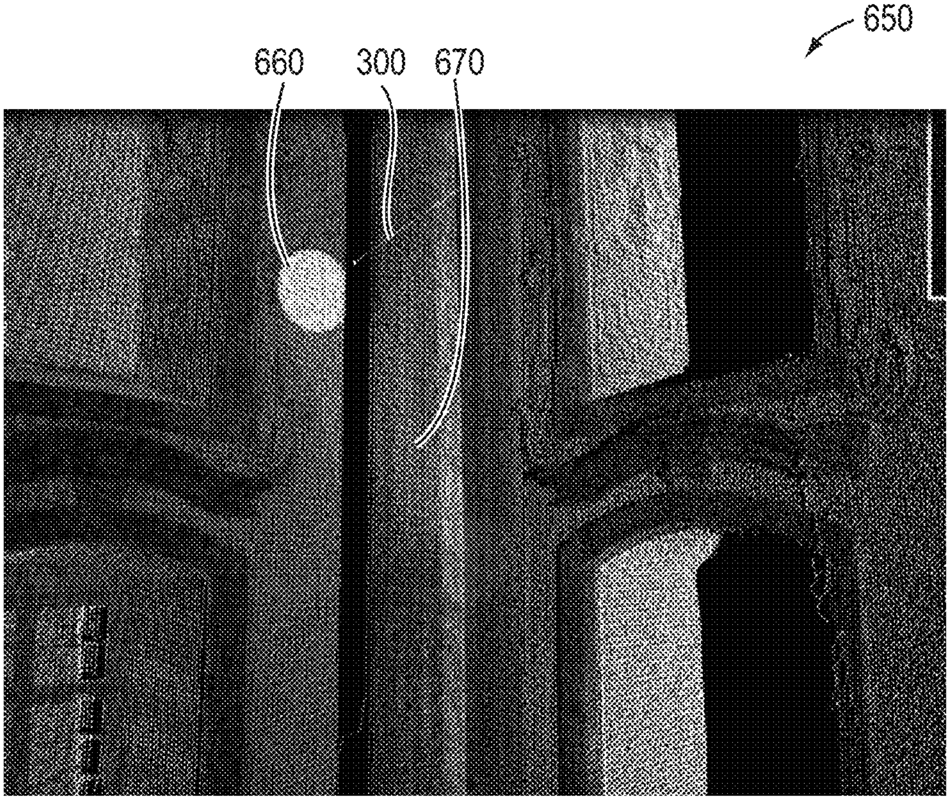


FIG. 6C

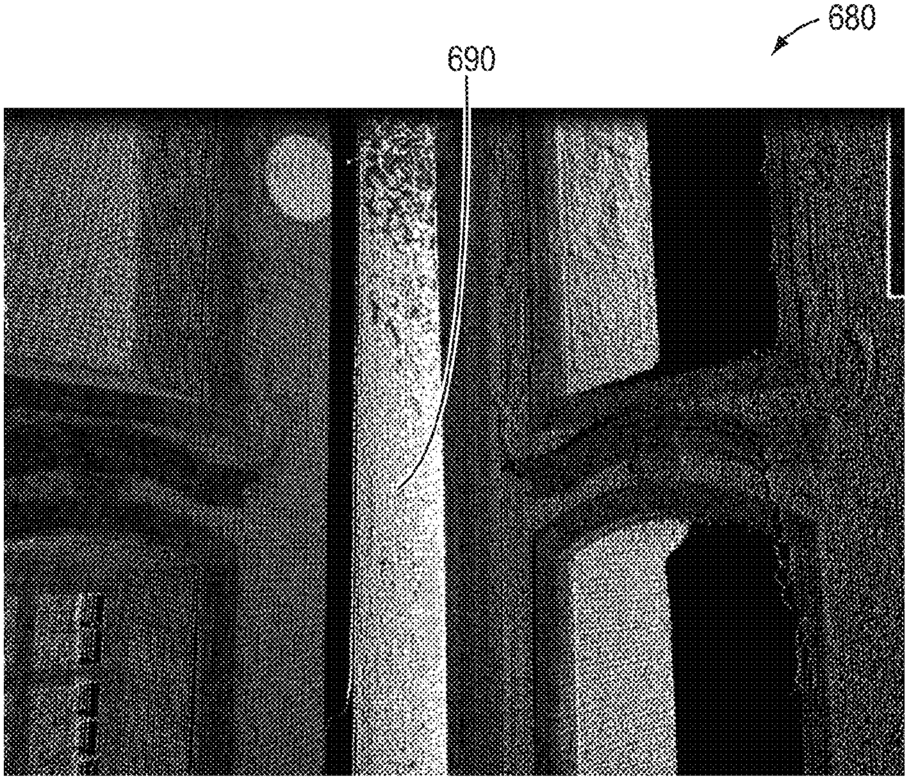
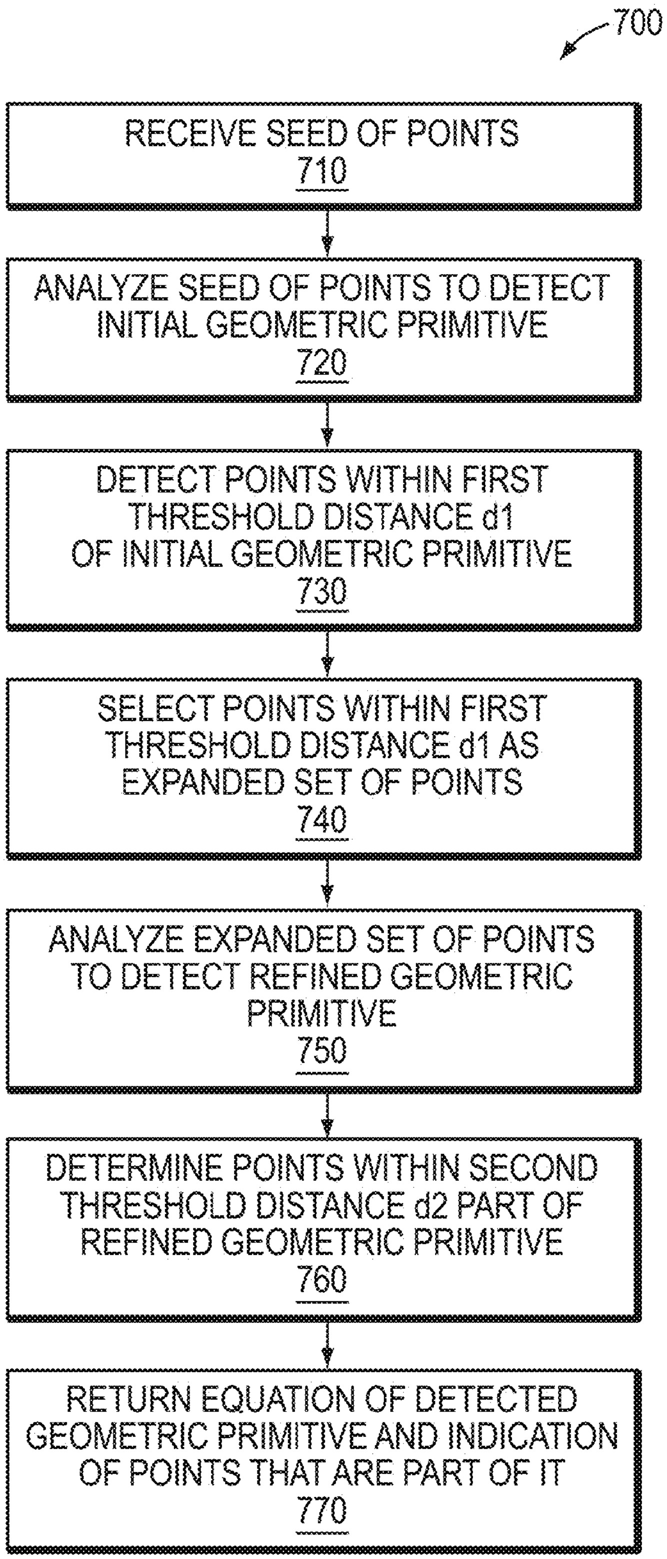


FIG. 6D


700
RECEIVE SEED OF POINTS
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ANALYZE SEED OF POINTS TO DETECT INITIAL GEOMETRIC PRIMITIVE
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DETECT POINTS WITHIN FIRST THRESHOLD DISTANCE d1 OF INITIAL GEOMETRIC PRIMITIVE
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760
RETURN EQUATION OF DETECTED GEOMETRIC PRIMITIVE AND INDICATION OF POINTS THAT ARE PART OF IT
770

FIG. 7

FIG. 8A

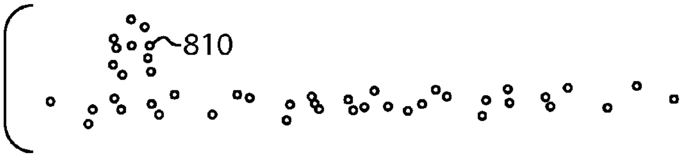


FIG. 8B

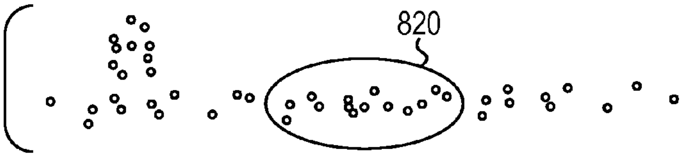


FIG. 8C

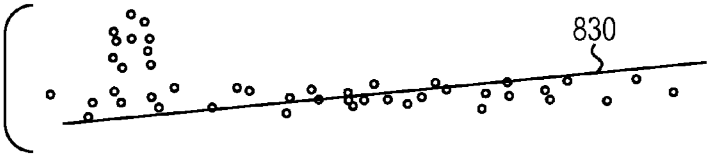


FIG. 8D

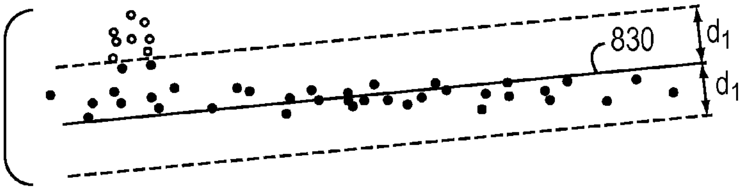


FIG. 8E

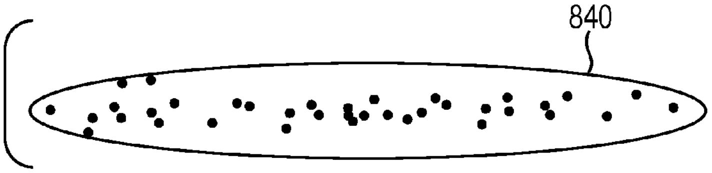


FIG. 8F

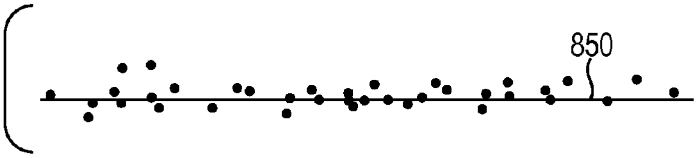
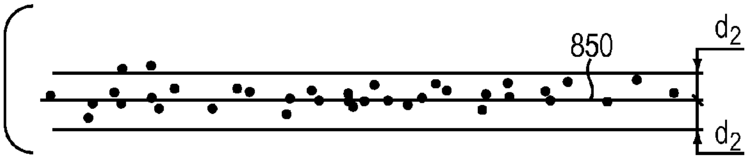


FIG. 8G



POINT CLOUD MODELING BASED ON USER-PROVIDED SEED

BACKGROUND

1. Technical Field

The present disclosure relates to point clouds, and more specifically, to techniques for reconstructing a vector-based model from point clouds.

2. Background Information

Three-dimensional (3-D) laser scanners are increasingly being used to accurately and quickly capture the shape of physical subjects, such as discrete objects, portions of structures, terrain, or other parts of the physical environment. Such scanners capture a point cloud of geometric samples on the surface of the subject. To accomplish such task, a 3-D laser scanner typically emits some form of coherent light and detects its reflection from the surface of the physical subject. Some 3-D laser scanners rely on time-of-flight. In a time-of-flight 3-D laser scanner, a laser emits pulses of coherent light in a grid-like pattern to scan the physical subject. A laser rangefinder finds the distance to the surface of the physical subject for each pulse of coherent light by timing the round-trip-time of the pulse of light, from its emission, to its reflection back to the laser rangefinder. Other 3-D laser scanners rely on some form of triangulation. Like a time-of-flight 3-D laser scanner, a triangulation 3-D laser scanner also emits coherent light in a grid-like pattern to scan the physical subject. However, rather than measure time-of flight, an offset camera is employed to look for the location where the coherent light strikes the subject (i.e. a laser dot). Depending on how far away the coherent light strikes the surface, the laser dot appears at different places in the camera's field of view, which can be used in a triangulation calculation to determine distance. In either case, a point cloud of geometric samples is produced by repeated application of the technique, where each point of the point cloud is associated with a particular x-axis, y-axis and z-axis position on the surface of the physical subject.

The points of the point cloud can be used to extrapolate the shape of the physical subject, which may be translated into a more readily used form through a reconstruction process. In reconstruction, the points of the point cloud are often used to produce a vector-based model, where the subject is represented by vector elements based on mathematical formulas, rather than by a large number of discrete points. For example, a first group of points that represent a surface may be converted to a first planar vector element. Likewise, a second group of points that represent another surface may be converted to a second planar vector element. In this manner, large numbers of discreet points may be reduced to a relatively small number of vector elements.

Unfortunately, reconstructing a vector-based model from a point cloud is typically a difficult process. Common reconstruction techniques include various automatic techniques and manual techniques.

In automatic techniques, a vector-based model is constructed by an automated process, where geometric primitives are automatically detected and converted into vector elements, for example by software. While seemingly appealing, such automatic techniques generally suffer from a number of shortcomings.

First, automatic techniques typically have no understanding of the geometry of the physical subject, and what points are significant or insignificant. The techniques generally rely upon a sensitivity parameter that indicates a threshold level of match between points and geometric primitives. Calibrating this sensitivity parameter may be extremely difficult, as it may vary among point clouds, depending on such things as the particular laser scanner employed to capture the point cloud, the particular physical subject scanned, distances between the scanner and subject, and the like. If it is set too thigh, a large number of very small geometric primitives may be detected, leading to a cluttered, confusing and potentially unusable vector-based model. For example, a particular physical feature (e.g., a door) may be represented by a large number of small geometric primitives. If a user desires to manipulate (e.g., move) the feature to test an alternative design, they would have to manipulate each an every one of the geometric primitives. This may be a daunting task. On the other hand, if the sensitivity parameter is set too low, a small number of very large geometric primitives may be detected, leading to a vector-based model that obscures or entirely omits important details. For example, a particular physical feature (e.g., a door) may be grouped together with other physical features (e.g., wall portions) and represented by a single geometric primitive. A user may be prevented from manipulating (e.g., moving) the feature to test an alternative design, absent times consuming manual operations to "separate" it from it from the other features.

Second, automatic techniques may be overly processing intensive, and therefore time consuming on typically computing hardware. Point clouds may include an extremely large number of discrete points, and it may require minutes or even hours to process an entire point cloud with an automatic technique on typical computing hardware. This delay may discourage the generation of vector-based models.

In manual techniques, a user is typically required to manually "draw" geometric primitives onto the point cloud, defining the extent of each geometric primitive. To "draw" geometric primitives, a user may manipulate a cursor to select a first specific point of the point cloud. The user may then move from this first point to one or more other specific points that are then selected. Collectively, the selected specific points define the exact bounds of the geometric primitive. However, such manual techniques generally suffer from a number of shortcomings.

First, it may be difficult for a user to accurately select specific points in a point cloud to "draw" the geometric primitive. When displayed on a typical display screen, e.g. a two-dimension (2-D) display screen, a point cloud typically appears completely flat. While each point in the point cloud may represent data at a different distance in 3-D space, when displayed on a 2-D display screen, a user may be unable to discern how far away from the viewing position a point is in 3-D space, without time-consuming additional operations. This may cause it to be difficult to accurately select specific points.

Second, manual approaches may be quite slow. The user may be burdened with precisely "drawing" each geometric primitive by selecting specific points that define their bounds. Given the effort and time required, it may discourage the generation of vector-based models.

Accordingly, there is a need for improved techniques for reconstructing a vector-based model from a point cloud that may address some, or all, of these shortcomings.

SUMMARY

In one embodiment, a semi-automated technique is used for reconstructing a vector-based model from a point cloud, which combines the intelligence of the user and the processing power of an electronic device. A user may use a user interface to select a number of points (referred to herein as a

"seed of points") in the point cloud that correspond to a particular feature in a physical subject. The selection may be performed using a special flashlight tool provided in the user interface, which facilitates rapid selection of a seed of points from among the points of the point cloud. After selection of the seed of points, automatic detection may be employed to detect a geometric primitive based on the seed of points. The automatic detection may utilize a special iterative algorithm to detect the geometric primitive, which, in part, detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points and detects a refined geometric primitive based on the expanded set of points. The automatic detection may return parameters of the refined geometric primitive, as well as an indication of points of the point cloud that are part of the geometric primitive. These points may be highlighted in the user interface. By repeating the selection of seeds of points, and automatic detection of geometric primitives, a vector-based model may be constructed from the point cloud.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description below refers to the accompanying drawings of example embodiments, of which:

FIG. **1** is a block diagram of an example electronic device, (e.g., a computer), in which a semi-automated technique for reconstructing a vector-based model from a point cloud may be employed;

FIG. **2** is an example sequence of steps for a semi-automated technique for reconstructing a vector-based model from a point cloud;

FIG. **3** is a schematic diagram of an example flashlight virtual tool that may be used;

FIG. **4** is a schematic diagram of a cross section of an example field of view of the example flashlight virtual tool;

FIG. **5** is an example sequence of steps for using the example flashlight virtual tool to select a seed of points in a point cloud;

FIG. **6**A is an example screen shot depicting the example flashlight virtual tool imposed within the 3-D space of an example point cloud;

FIG. **6**B is an example screen shot depicting points being selected by the example flashlight virtual tool, with their highlighting changed to indicate their current selection;

FIG. **6**C is an example screen shot depicting additional points being selected by the example flashlight virtual tool;

FIG. **6**D is an example screen shot showing points associated with a returned geometric primitive highlighted;

FIG. **7** is an example sequence of steps for performing automatic detection of a geometric primitive using an example iterative algorithm;

FIG. **8**A is an illustration of a portion of an example point cloud associated with a physical feature;

FIG. **8**B is an illustration of an example seed of points for the physical feature of FIG. **8**A;

FIG. **8**C is an illustration of an example initial geometric primitive that is detected as a best match for the example seed of points of FIG. **8**B;

FIG. **8**D is an illustration of a first threshold distance, d_1, measured from the example initial geometric primitive of FIG. **8**C;

FIG. **8**E is an illustration of an expanded set of points derived from the initial geometric primitive based on the first threshold distance, d_1, shown in FIG. **8**D;

FIG. **8**F is an illustration of an example refined geometric primitive that is detected as a best match for the expanded set of points from FIG. **8**E;

FIG. **8**G is an illustration of example points that are part of the refined geometric primitive of FIG. **8**F, the points selected based on a second threshold distance, d_2, from the refined geometric primitive;

DETAILED DESCRIPTION

FIG. **1** is a block diagram of an example electronic device **100**, (e.g., a computer), in which a semi-automated technique for reconstructing a vector-based model from a point cloud may be employed. The electronic device **100** includes at least one processor **110** coupled to a host bus **120**. The processor **110** may be any of a variety of commercially available processors, such as an Intel x86 processor, or another type of processor. A volatile memory **130**, such as a Random Access Memory (RAM), is coupled to the host bus **120** via a memory controller **125**. The memory **130** is configured to store at least a portion of computer-executable instructions and data for an operating system **135** while the electronic device **100** is operating. In addition, the memory **130** may store at least portions of a computer aided design (CAD) software platform **140** on which a wide variety of task-specific applications may be based. The CAD software platform **140** may provide base functionality relating to object management, geometric relationships, information and standards management, visualization, drawing and report extraction, and the like. In one embodiment, the CAD software platform is the MicroStation® V8i CAD software platform, available from Bentley Systems Inc. A number of task-specific applications, including a visualization and conversion application **142**, may provide additional functionality leveraging the base functionality of the CAD software platform **140**. In one embodiment, the visualization and conversion application **142** is the Bentley® Descartes visualization and conversion application, available from Bentley Systems Inc. Among other things, the visualization and conversion application **142** may include a user interface **144**, a selection tool module **146**, and a conversion engine **148**, that collectively may be employed to implement a semi-automated technique for reconstructing a vector-based model from a point cloud, as discussed in more detail below.

The host bus **120** of the electronic device **100** is coupled to an input/output (I/O) bus **150** through a bus controller **145**. A video display subsystem **155** may include a display screen **170**, such as a 2-D display screen, and hardware to drive the display screen. The video display subsystem **155** is coupled to the I/O bus **150**. The display screen **170**, among other functions, may show a visual portion of the user interface of the visualization and conversion application **142**. One or more input devices **160** are provided and used for interaction with the electronic device **100**, and the visualization and conversion application **142** executing on the electronic device. The one or more input devices **160**, may include 2-D input devices, such as a 2-D mouse. A persistent storage device **165**, such as a hard disk drive, a solid-state drive, or other type or persistent data store, is coupled to the I/O bus **150**, and may persistently store computer-executable instructions and data, that are available to be loaded to the volatile memory **130** when needed. For example, computer-executable instructions and data for the operating system **135**, and the CAD software platform **140**, and the visualization and conversion application **142**, may be stored in the persistent storage device **165**. The I/O bus **150** may further be coupled to a network interface **180** that interfaces with a computer network (not shown). The computer network may allow communication between the electronic device **100** and other devices, using any of a number of well known networking protocols, including wireless networking protocols, to permit a variety of distributed, collaborative or remote computing configurations.

A user may utilize the user interface **144** of the above mentioned visualization and conversion application **142** to view on the display screen **170** a point cloud. The point cloud may be composed of geometric samples descriptive of the shape of a physical subject, such as a discrete object, portions of a structure, terrain, or other parts of the physical environment. The geometric samples may be captured by a 3-D laser scanner or other scanning device.

A semi-automated technique for reconstructing a vector-based model from a point cloud may be employed that combines the intelligence of the user and the processing power of the electronic device **100**. A user may use the user interface **144** of the visualization and conversion application **142** to select a number of points (referred to herein as "seed of points") in the point cloud that correspond to a particular feature in the physical subject. The selection may be aided by a special flashlight tool provided by that selection tool module **146**, which facilitates rapid selection of a seed of points from among the points of the point cloud. After selection of a seed of points, the conversion engine **148** of the visualization and conversion application **142** may then be called upon to automatically detect a geometric primitive based on the seed of points. The conversion engine **148** may employ a special iterative algorithm to detect the geometric primitive, which, in part, detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points, and detects a refined geometric primitive based on the expanded set of points. The conversion engine **148** may return parameters of the refined geometric primitive, as well as an indication of points of the point cloud that are part of the geometric primitive. These points may be highlighted in the user interface, and the user prompted to confirm that the detected geometric primitive meets expectations. By repeated selection of seeds of points, and automatic detection of geometric primitives, a vector-based model may be constructed from the point cloud of discrete points.

The seeds of points selected by a user need not be precisely selected. That is, every point in a seed of points need not be actually derived from the particular physical feature. The points of the seed of points may be considered to "correspond" to a particular physical feature provided that more points of the seed of points are derived from that particular physical feature than are derived from any other single physical feature of the subject. Further, the points of the seed of points need not define the exact bounds of the physical feature. They may simply represent points "on" the physical feature.

Further the automatic detection performed by the conversion engine **148** need not be over the entire point cloud. Only a subset of the overall point cloud may be considered by the conversion engine **148**, such that the detection of the geometric primitive may occur quite rapidly. Further, a sensitivity parameter employed by the conversion engine **148** may be specific to the current automatic detection, such that the sensitivity parameters may differ on a feature-by-feature basis.

FIG. **2** is an example sequence of steps for a semi-automated technique for reconstructing a vector-based model from a point cloud. At step **210**, at least a portion of a point cloud that represents a physical subject is displayed on the display screen **170** by the user interface **144** of the visualization and conversion application **142**. At optional step **220**, a selection is received from the user of a type of geometric primitive that it to be detected. The selection may be received using one or more input devices **160**. The type of geometric primitive may be a plane, a cylinder, a prism, a sphere, a pyramid, a torus, or other supported primitive.

At step **230**, a selection is received from the user of a seed of points of the point cloud that correspond to a particular physical feature in the physical subject. As mentioned above, every point in the seed of points need not be actually derived from the particular physical feature, nor do they need to define the bounds of the physical feature. A "quick and careless" seed selection is generally sufficient. To permit such selection, the selection tool module **146** may provide a special flashlight virtual tool that facilitates rapid selection of a seed of points from among the points of the point cloud. Further details of an example flashlight virtual tool are provided below in connections with FIGS. **3**-**6**.

At step **240**, the conversion engine **148** performs an automatic detection of a geometric primitive selected in step **220**, based on the seed of points from step **230**. If a type was selected in optional step **220**, the automatic detection will detect a geometric primitive of the selected type. Alternatively, the conversion engine **148** may determine a "best" type for the geometric primitive. The automatic detection may account for non-uniformity in the particular physical feature and noise in the seed of points, resulting from, for example, limited accuracy of the 3-D laser scanner or other scanning device. The conversion engine **148** may employ a special iterative algorithm to detect the geometric primitive that, in part, detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points, and detects a refined geometric primitive based on the expanded set of points. Further details of an example iterative algorithm are provided below in connections with FIGS. **7**-**8**. The conversion engine **148** may return parameters of the detected geometric primitive (e.g., an equation of the geometric primitive), as well as an indication of points of the point cloud that are part of the detected geometric primitive.

At step **250**, the user interface **144** may highlight those points that are part of the detected geometric primitive, and the user may be prompted to confirm that the detected geometric primitive meets expectations.

At step **260**, a determination is made whether all desired geometric primitives have been detected in the point cloud. If so, execution proceeds to step **270**, were a vector-based model is produced from the geometric primitives, with vector elements corresponding to each detected geometric primitive. The vector based model may be stored in memory **130**. If not, execution loops back to step **220**, and the sequence of steps repeated for a different physical feature.

As discussed above, the selection of the seed of points that correspond to a physical feature of the subject may be aided by a special flashlight virtual tool. FIG. **3** is a schematic diagram of an example flashlight virtual tool **300** that may be used. The flashlight virtual tool **300** has a position within the 3-D space of the point cloud. This position may be changed by a user using an input device **160**. The flashlight virtual tool **300** includes a body **310**. The body may be graphically displayed as a line or cylinder within the 3-D space of the point cloud. Alternatively, the body may be graphically displayed as an icon reminiscent of a physical flashlight. The flashlight virtual tool **300** also includes a field of view **320**. The field of view **320** may be disposed along an axis **330** of the flashlight virtual tool **300**, between a first limit **340** and a second limit **350**. When the flashlight virtual tool **300** is positioned in 3-D space proximate to points of a point cloud, highlighting effects may be imposed upon points within the field of view **320**, such that it appears that a stream of light is being emitted upon the points within the field of view. In one embodiment, the highlighting effects may change (e.g., a color may change) as points are selected or other actions are performed, to provide a visual indication to the user. Alternatively, the highlighting effects may remain constant.

FIG. **4** is a schematic diagram of a cross section of an example field of view **320** of the example flashlight virtual tool **300**. In this example, the field of view **320** is shaped as a cone. The cone may have its apex at the first limit **340** and its base at the second limit **350**, with its axis aligned along the axis **330** of the flashlight virtual tool **300**. The cone may be further defined by an opening angle θ. In other implementations, the field of view **320** may be shaped in a variety of different manners. For example, the field of view **320** may be shaped as a pyramid, a cylinder, a prism, multiple cones, multiple pyramids, or any of a variety of other shapes or combinations of shapes.

Points of the point cloud that fall within the field of view may be highlighted. In one embodiment, the highlighting effect may involve changing points within the field of view to a particular color, or tinting points within the field of view with a particular color. Different highlighting effects may involve changing or tinting points to different colors. As the user moves the flashlight virtual tool within the point cloud, the points of the point cloud that fall within the field of view change. As this occurs, the points of the point cloud that are highlighted may be updated in substantially real-time, to approximate the appearance of a real flashlight being moved while shining upon among real objects.

The selection tool module **146** may provide a selection button for the flashlight virtual tool **300**. When activated, any points currently highlighted by the flashlight virtual tool **300** may be selected and added to a selection set maintained in memory. If the flashlight virtual tool **300** is moved within the user interface **144** while the selection button is still activated, such that additional points become highlighted, these additional points may be added to the selection set. Depending on the implementation, the selection button may take on any of a variety of different forms. For example, the selection button may be one or more physical buttons of an input device **160**, such as a mouse button or keyboard key. Alternatively, the selection button may be one or more virtual buttons or other controls provided by the user interface **144**, which may be displayed and selected on the display screen **170**.

FIG. **5** is an example sequence of steps **500** for using the example flashlight virtual tool **300** to select a seed of points in a point cloud. At least some of the steps **500** of FIG. **5** may be implemented as part of step **230** of FIG. **2**.

At step **510**, the selection tool module **146** may impose the flashlight virtual tool **300** within the 3-D space of the point cloud, and show the flashlight virtual tool **300** on the display screen **170**.

FIG. **6**A is an example screen shot **600** depicting the example flashlight virtual tool **300** imposed within the 3-D space of an example point cloud. In FIG. **6**A, the example point cloud represents a portion of a structure, with columns, window openings, and other architectural features. However, it should be understood that the point cloud may represent any of a variety of other types of physical subjects. The points **610** that fall within the field of view of the flashlight virtual tool **300** may be highlighted with a first color, e.g. green. A user may move the flashlight virtual tool **300** about by manipulating an input device **160**, such that different points fall within the field of view, and are highlighted with the first color.

At step **520**, the selection tool module **146** detects that the user has activated the selection button for the flashlight virtual tool **300**. At step **530**, the selection tool module **146** selects points that currently fall within the field of view of the flashlight virtual tool **300**, and adds these points to an initially-empty selection set stored in memory **130**. The highlighting effect applied to the points may be changed to indicate their current selection.

FIG. **6**B is an example screen shot **620** depicting points **630** being selected by the example flashlight virtual tool **300**, with their highlighting changed to indicate their current selection. The highlighting may be of a second color, e.g., light blue, different from the first color.

At step **540**, while the selection button is still activated, the flashlight virtual tool **300** may be moved within the 3-D space of the point cloud, such that additional points pass within the field of view, and previously selected points fall out of the field of view. At step **550** the additional points may be added to the selection set stored in memory. The additional points may have their highlighting changed to indicate their current selection. For example, their highlighting may be changed to the second color, e.g., light blue. Further, the previously selected points may have their highlighting changed to indicate their previous selection. For example, their highlighting may be changed to a third color, e.g., dark blue. The highlighting may provide visual feedback to the user, allowing him or her to readily discern what has been selected so far. This may, for example, allow the user to determine if an adequate number of points have been selected for the particular feature that is to be modeled. FIG. **6**C is an example screen shot **650** depicting additional points being selected by the example flashlight virtual tool **300**. Points **660** currently within the field of view of the flashlight virtual tool **300**, and the subject of current selection, are highlighted in the second color, e.g., light blue. Points **670** subject to pervious selection are shown highlighted in the third color, e.g., dark blue.

At step **560**, the selection tool module **146** detects that the user has deactivated the selection button for the flashlight virtual tool **300**. At step **570**, in response to the deactivation, the points of the selection set are returned as a seed of points.

As discussed above, the seed of points may be used by the conversion engine **148** to perform an automatic detection of a geometric primitive. FIG. **7** is an example sequence of steps **700** for performing automatic detection of a geometric primitive using an example iterative algorithm. At least some of the steps **700** of FIG. **7** may be implemented as part of step **240** of FIG. **2**.

At step **710**, the seed of points is received by the conversion engine **148** from the selection tool module **146**. As discussed above, the seed of points, in general, corresponds to a physical feature of the physical subject, however typically not every point is actually derived from the particular physical feature, and there is generally noise among the points resulting from non-uniformity in the particular physical feature and limited accuracy of the scanning device.

FIG. **8**A is an illustration of a portion of an example point cloud associated with a physical feature. In this example, the portion is a flat surface. For purposes of illustration, the portion is abstracted to be a 2-D representation. However, it should be understood that the techniques are applicable, among other uses, to point clouds that inhabit 3-D space and represent 3-D physical subjects. A projection of points **810** may extend from the flat surface due to non-uniformity in the flat surface. Further, the points may be generally dispersed as a result of noise introduced by the scanning process.

FIG. **8**B is an illustration of an example seed of points **820** for the physical feature of FIG. **8**A.

At step **720**, the conversion engine **148** analyzes the seed of points to detect an initial geometric primitive that best matches the seed. If the user selected a type of geometric primitive in optional step **220** of FIG. **2**, the initial geometric primitive may be of the selected type. Alternatively, the initial geometric primitive may be of a type deters mined to be "best" by the conversion engine **148**. The initial geometric primitive represents the particular physical feature that corresponds to the seed of points. The conversion engine **148** may employ a library to perform the actual analysis and detection of the initial geometric primitive. In one implementation, the library may be the Point Cloud Library (PCL) image and point cloud processing library, available as an open source library. The PCL image and point cloud processing library employs a random sample consensus (RANSAC) algorithm that involves selecting a sample set, computing a model, computing and counting inliers, and repeating these operations until a sufficient level of confidence of fit is achieved in a geometric primitive. In other implementations, rather than use the PCL image and point cloud processing library, a variety of other libraries may be employed. In still other alternative implementation, no library may be employed, and the analysis and detection may be performed by code internal to the conversion engine **148**.

FIG. **8**C is an illustration of an example initial geometric primitive **830** that is detected as a best match for the seed of points **820** of FIG. **8**B. In this example, the initial geometric primitive is an initial plane. The initial plane may closely match the points of the seed of points **820**, but may poorly match for the overall physical feature of the physical subject.

At step **730**, the conversion engine **148** detects points in the point cloud that are within a first threshold distance, d_1, of the initial geometric primitive **830**. The first threshold distance, d_1, may be selected such that points which deviate due to noise are substantially included within the first threshold distance, d_1, yet points which deviate due to non-uniformity in the physical feature are substantially excluded. The selection of d_1 may be made by the user, or by an automated process.

FIG. **8**D is an illustration of a first threshold distance, d_1, measured from the example initial geometric primitive **830** of FIG. **8**C. As can be seen, despite noise, substantially all the points of the physical feature fall within the first threshold distance, d_1, of the initial plane with the exception of the projection of points **810** resulting from non-uniformity in the surface.

At step **740**, the conversion engine **148** selects the points that fall within the first threshold distance, d_1, as an expanded set of points.

FIG. **8**E is an illustration of an expanded set of points **840** derived from the initial geometric primitive **830** based on the first threshold distance, d_1, from FIG. **8**D.

At step **750**, the conversion engine **148** analyzes the expanded set of points to detect a refined geometric primitive that best matches the expanded set of points. Again, the conversion engine **148** may employ an external library to perform the actual analysis and detection, for example, the PCL image and point cloud processing library may be called.

FIG. **8**F is an illustration of a refined geometric primitive **850** that is detected as a best match for the expanded set of points from FIG. **8**E. Here, the refined geometric primitive **850** is a refined plane. The refined plane may provide a much better match to the overall physical feature than the initial plane.

At step **760**, the conversion engine **148** may determine points of the point cloud that are part of the refined geometric primitive **850**. Specifically, points of the point cloud that are within a second threshold distance, d_2, of the refined geometric primitive may be considered to be part of the refined geometric primitive **850**. The second threshold distance, d_2, may be selected to be less than the second threshold distance, d_1, to exclude points unlikely to be a part of the physical feature. The value of d_2 may be specified by the user or determined automatically by the conversion engine **148**.

FIG. **8**G is an illustration of example points that are part of the refined geometric primitive **850** of FIG. **8**F, the points selected based on a second threshold distance, d_2, from the refined geometric primitive **850**. As can be seen, at least some points from the projection **810** included in the expanded set of points **840**, do not fall within the second threshold distance, d_2, and are therefore excluded from the points considered to be part of the refined geometric primitive.

At step **770**, the refined geometric primitive is used as the detected geometric primitive, and the conversion engine **148** returns an equation of there detected geometric primitive and an indication of the points that are part of the detected geometric primitive.

As discussed above, provided that the detected geometric primitive meets the user's expectations, the returned equation may be used for a vector element of a vector-based model. To determine if the detected geometric primitive meets the user's expectations, the returned indication of points may be used to highlight points associated with the geometric primitive in the displayed point cloud.

Referring back to the example shown in FIGS. **6**A-**6**C, FIG. **6**D is an example screen shot **680** showing points **690** associated with a returned geometric primitive highlighted. The points **690** may be highlighted in a manner different than the other highlighting, for example, by changing their color to fourth color, e.g., yellow. From the highlighting, the user may rapidly determine if the detected geometric primitive is consistent with their expectations.

While the above description discusses various embodiments of the present disclosure, it should be apparent that a number of modifications and/or additions may be made without departing from the disclosure's intended spirit and scope. It should be understood that the above described techniques may be implemented in software, in hardware, or a combination thereof. A software implementation may include executable instructions that implement applications stored in a non-transitory computer-readable medium, such as a volatile or persistent memory device, a hard-disk, a compact disk (CD), etc. A hardware implementation may include processors, memory chips, programmable logic circuits, application specific integrated circuits, and/or other types of hardware components. Further, a combined software/hardware implementation may include both computer-executable instructions stored in a non-transitory computer-readable medium, as well as one or more hardware components. Accordingly, it should be understood that the above descriptions are meant to be taken only by way of example.

What is claimed is:

1. A method for reconstructing a vector-based model from a point cloud that represents a physical subject comprising:

displaying at least a portion of the point cloud that represents the physical subject on a display screen of an electronic device, each point of the point cloud associated with a position in three-dimensional (3-D) space;

receiving a selection of a seed of points in the point cloud that correspond to a particular physical feature of the physical subject, the selection received with a flashlight virtual tool having a field of view, points of the point cloud falling within the field of view being used as the seed of points;

performing an automatic detection of a geometric primitive based on the seed of points, using an iterative algorithm that detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points that include points outside of the seed of points, and detects a refined geometric primitive based on the expanded set of points, wherein the refined geometric primitive is returned as the detected geometric primitive; and

producing a vector-based model using the detected geometric primitive.

2. The method of claim **1**, further comprising:

highlighting points of the point cloud that are a part of the detected geometric primitive in the portion of the point cloud that is being displayed on the display screen of the electronic device.

3. The method of claim **1**, further comprising:

receiving a selection, by an input device of the electronic device, of a type of geometric primitive to be detected, and

wherein the performing performs an automatic detection of a geometric primitive of the type.

4. The method of claim **1** further comprising:

determining additional geometric primitives are to be detected; and

repeating the receiving and performing until all desired geometric primitives have been detected.

5. The method of claim **1**, wherein the receiving further comprises:

imposing the flashlight virtual tool within the 3-D space of the point cloud;

detecting activation of a selection button for the flashlight virtual tool;

adding points that fall within the field of view to a selection set; and

returning the points of the selection set as the seed of points.

6. The method of claim **5**, further comprising:

detecting the flashlight virtual tool being moved, while the selection button is still activated; and

adding additional points that pass within the field of view, while the selection button is still activated, to the selection set.

7. The method of claim **5** further comprising:

prior to detecting activation of the selection button, highlighting points falling within the field of view with a first color; and

after activation of the selection button, highlighting points falling within the field of view with a second color different than the first color.

8. The method of claim **7**, further comprising:

highlighting points that are the subject of previous selection with a third color, different than the first and second colors.

9. The method of claim **1**, wherein the performing detects the initial geometric primitive and detects the refined geometric primitive by calling a library that employs a random sample consensus (RANSAC) algorithm.

10. The method of claim **1**, wherein the performing uses the initial geometric primitive to determine the expanded set of points by:

detecting points in the point cloud that are within a first threshold distance of the initial geometric primitive; and

selecting points that fall within the first threshold distance as the expanded set of points.

11. The method of claim **1**, wherein the performing further comprises:

detecting points in the point cloud that are within a second threshold distance of the refined geometric primitive; and

returning points that fall within the second threshold distance as points that are part of the detected geometric primitive.

12. An apparatus for reconstructing a vector-based model from a point cloud that represents a physical subject, comprising:

a display screen;

a processor; and

a memory coupled to the processor and configured to store instructions for a visualization and conversion application that are executable by the processor, the instructions for the visualization and conversion application including instructions for:

a user interface configured to display at least a portion of the point cloud that represents the physical subject, each point of the point cloud associated with a position in three-dimensional (3-D) space,

a selection tool module configured to receive a selection of a seed of points in the point cloud that correspond to a particular physical feature of the physical subject, and

a conversion engine configured to perform an automatic detection of a geometric primitive based on the seed of points, using an iterative algorithm that detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points that include points outside of the seed of points, and detects a refined geometric primitive based on the expanded set of points,

wherein the conversion engine is further configured to produce a vector-based model using the detected geometric primitive.

13. The apparatus of claim **12**, wherein the conversion engine is configured to detect the initial geometric primitive and detect the refined geometric primitive by calls to a library that employs a random sample consensus (RANSAC) algorithm.

14. The apparatus of claim **12**, wherein the conversion engine is configured to use the initial geometric primitive to determine an expanded set of points by detection of points in the point cloud that are within a first threshold distance of the initial geometric primitive, and selection of points that fall within the first threshold distance as the expanded set of points.

15. The apparatus of claim **12**, wherein the conversion engine is configured to determine points of the point cloud that are part of the refined geometric primitive as points that are within a second threshold distance of the refined geometric primitive.

16. A method for reconstructing a model from a point cloud that represents a physical subject, comprising:

displaying at least a portion of the point cloud that represents the physical subject on a display screen of an electronic device, each point of the point cloud associated with a position in three-dimensional (3-D) space;

receiving a selection from a user of a seed of points in the point cloud that correspond to a particular physical feature of the physical subject;

performing an automatic detection of a geometric primitive based on the seed of points, using an iterative algorithm that detects an initial geometric primitive based on the seed of points, uses the initial geometric primitive to determine an expanded set of points that include points outside of the seed of points, and detects a refined geometric primitive based on the expanded set of points, wherein the refined geometric primitive is returned as the detected geometric primitive; and

producing a model using the detected geometric primitive.

17. The method of claim **16**, wherein the receiving is performed based on a selection tool having a field of view, wherein points of the point cloud falling within the field of view are used as the seed of points.

18. The method of claim **17**, wherein the selection tool is a flashlight virtual tool.

19. The method of claim **18**, wherein the receiving further comprises:

imposing the flashlight virtual tool within the 3-D space of the point cloud;

detecting activation of a selection button for the flashlight virtual tool;

adding points that fall within the field of view to a selection set; and

returning the points of the selection set as the seed of points.

20. The method of claim **19**, further comprising:

detecting the flashlight virtual tool being moved, while the selection button is still activated; and

adding additional points that pass within the field of view, while the selection button is still activated, to the selection set.

21. The method of claim **16**, wherein the performing uses the initial geometric primitive to determine the expanded set of points by:

detecting points in the point cloud that are within a first threshold distance of the initial geometric primitive; and

selecting points that fall within the first threshold distance as the expanded set of points.

22. The method of claim **21**, wherein the performing further comprises:

detecting points in the point cloud that are within a second threshold distance of the refined geometric primitive; and

returning points that fall within the second threshold distance as points that are part of the detected geometric primitive.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 9,189,888 B1	Page 1 of 1
APPLICATION NO.	: 13/740761	
DATED	: November 17, 2015	
INVENTOR(S)	: Cté	

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification:
Col. 2, line 22 should read:
design, absent time-consuming manual operations to “sepa-

Col. 9, line 2 should read:
geometric primitive may be of a type determined to be

Signed and Sealed this
Twenty-sixth Day of April, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office